Can low back loading during lifting be reduced by placing one leg beside the object to be lifted?

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Research Report

Can Low Back Loading During Lifting Be Reduced by Placing One Leg Beside the Object to Be Lifted?

Background and Purpose. Lifting technique could, through its effect on low back loading, affect the risk of developing low back pain. In this study, 2 lifting techniques (a straddle technique and a 1-leg kneeling technique), which aimed to reduce low back loading by placing one leg beside a load, were compared with stoop lifting and squat lifting with respect to their effect on low back loading. **Subjects.** Twelve men with no history of low back pain participated in the study. **Methods.** The subjects lifted wide and narrow 20-kg boxes from 2 initial hand heights. With measured kinematics, ground reaction forces, and electromyography, 3-dimensional spinal forces were calculated. **Results.** When the subjects lifted a narrow box from a 290-mm height, peak L5–S1 compression forces were 5,060 (SD=827), 3,980 (SD=701), 4,208 (SD=762), and 4,719 (SD=1,015) N for the stoop, squat, straddle, and kneeling techniques, respectively. When the subjects lifted a wide box from 50 mm, spinal compression forces were much higher and distributed differently over lifting techniques: 5,926 (SD=610), 6,868 (SD=924), 6,472 (SD=1,042), and 6,064 (SD=968) N, respectively. **Discussion and Conclusion.** The authors conclude that no single lifting technique can be advised for all lifting conditions. [Kingma I, Faber GS, Bakker AJM, van Dieën JH. Can low back loading during lifting be reduced by placing one leg beside the object to be lifted? *Phys Ther.* 2006;86:1091–1105.]

Key Words: *Back injuries, Biomechanics, Ergonomics.*

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What problems did the researchers set out to study, and why?
Conflicting evidence exists on what strategy is most effective in preventing back injury during lifting. The researchers examined how low back loading is affected by lifting strategy and the size and height of the load being lifted. They hypothesized that placing one foot beside the load to be lifted while assuming a kneeling position with the contralateral limb would reduce spinal loading but would induce asymmetrical spinal loading when lifting wide loads.

Who participated in the study?
Twelve male subjects with no history of low back pain (mean age of 26.1 years, SD=26.1).

What new information does this study offer?
Large extensor moments about the joints of the lumbar vertebral column are produced by the paravertebral musculature during lifting. These moments result in large compressive and shear forces acting between each pair of vertebrae, which may result in injury to the intervertebral disk, muscles, and ligaments. Although lifting from a squat position with the lumbar spine maintained in lordosis is a commonly taught strategy, there is little evidence to support that this posture reduces compressive and shear forces acting on the spinal segments. Existing evidence suggests that compressive and shear forces acting on the lumbar spine are most influenced by load moment, lifting speed, and acceleration. This study showed that the width of an object and the height from which an object is lifted are more important determinants of forces acting on the lumbar spine than the strategy used to perform the lift. The study further suggests that squatting may be an effective technique to reduce compressive forces acting at L5–S1 when lifting narrow loads, but straddling and stooping techniques are more effective at reducing compressive forces when lifting wider loads from the floor. Asymmetrical spinal loading and increased lateral shear force was induced in this study when subjects lifted loads using the kneeling straddle technique as described.

How did the researchers go about the study?
The authors of this study measured kinematics, ground reaction forces, and electromyographic trunk muscle activity as subjects lifted wide (600 mm) and narrow (300 mm) 20-kg boxes from two heights (290 mm and 50 mm). Researchers constructed a model that allowed them to calculate 3-dimensional forces acting on the lumbar spine for each of 4 lifting techniques in each of the tested conditions. The lifting techniques tested were squat lifting (lifting with a straight lumbar spine while flexing at the knees), stoop lifting (lifting with straight knees while flexing the lumbar spine), straddle lifting (straddling the load in standing with one foot to the side of the load and the other behind the load), and the kneeling technique (straddling the load with one foot to the side of the load while kneeling on the contralateral knee behind the load). Videotaped instruction, guided practice, and verbal cueing in lifting techniques were provided to all subjects prior to testing. The researchers combined kinematic data from light-emitting diode markers with anthropometric and force-plate data to construct a 3-dimensional model. This model was then utilized to estimate net moments and compression and shear forces occurring at the L5–S1 spinal intervertebral disk during testing.

How might the results of this study apply to patients who are treated by physical therapists from this point forward?
Physical therapists should advise patients to avoid lifting wide objects from the floor whenever possible. When patients are required to lift objects from floor level, adjusting the posture to the size and placement of a load during lifting to minimize the horizontal distance from the low back to the load is advisable, based on current evidence. Teaching a patient to kneel on one knee while straddling a wide load on the floor may reduce the compressive and shear forces acting on the lumbar spine during lifting by bringing the load close to the body without placing the lumbar spine in full flexion, as seen in the stoop technique. When objects are narrow enough to fit between the feet, squat lifting can reduce compressive forces on the spine.

What are the limitations of the study, and what further research is needed?
This study was performed on a small, homogenous sample of healthy, young men. The results are not generalizable to women or individuals with back pain. Furthermore, the mechanics of the spine in older individuals who are likely to have degenerative changes of the spine may be different from the sample tested in this study. Finally, this study doesn't account for individual variations in lifting techniques that may occur due to musculoskeletal issues (such as knee pain or muscle flexibility) or due to asymmetry in load placement.

[Kingma I, Faber GS, Bakker AJM, van Dieën JH. Can low back loading during lifting be reduced by placing one leg beside the object to be lifted? *Phys Ther.* 2006;86:1091–1105.]

Summarized by Evan Johnson, PT, DPT, MS, OCS, MT, Assistant Professor of Clinical Physical Therapy, Program in Physical Therapy, Columbia University, New York, NY.

Manual materials handling is considered to be an important risk factor for the development of low back pain because it can lead to spinal loading that exceeds tissue tolerance.[1,2] In rehabilitation programs for patients with low back pain, such as intensive back schools, training in ergonomic factors during manual materials handling is often included.[3,4] A systematic review[5] showed that there is moderate evidence that back schools in occupational settings are, in short-term follow-up and medium-term follow-up, more effective (in terms of pain reduction, functional status, and return to work) than other interventions for nonspecific low back pain. Effective instruction on how to lift objects depends on knowledge of the effects of ergonomic factors on low back loading. For some of those factors, such as lifting speed[6,7] and the horizontal[8,9] and vertical[9–12] distances of the load from the worker, effects are well established and predictable on the basis of the principles of mechanics.

With respect to lifting technique, the evidence is still conflicting. Reviews focusing on squat lifting (lifting with a straight back while bending the knees) versus stoop lifting (lifting with straight knees while bending the back) indicated that the evidence regarding the best technique (ie, the technique resulting in the lowest loading of the low back) is inconclusive.[13–15] This inconsistency may be related to the influence of specific details of a lifting condition on the effects of a lifting technique. In a recent study,[10] it was shown that effects of lifting technique on low back loading changed or could even reverse when the initial lifting height and foot position relative to the load were changed. Kinematic factors underlying the inconsistency of effects of lifting technique appeared to be the horizontal L5–S1 position relative to the load, the upper-body acceleration, and lumbar flexion.[10] The decrease in low back loading attributable to the decrease in lumbar flexion in squat lifting relative to stoop lifting was often smaller than the increase in low back loading caused by the larger horizontal distance from L5–S1 to the load.[10] Therefore, it seems that the horizontal distance from L5–S1 to the load is the most important factor determining how a lifting technique affects low back loading.

There are at least 3 strategies for reducing the horizontal distance between L5–S1 and the load. One strategy is to lift the load in between the feet. This strategy has been shown to reduce low back loading in both the stoop lift and the squat lift.[10] However, placing both feet beside the load is difficult when lifting larger objects. In both stoop lifting and squat lifting, subjects did not lift the load in between the feet when they were not explicitly instructed to do so.[10] One reason may be that lifting with both feet beside the load is rather unstable. A second strategy for bringing L5–S1 closer to the load is to place only one leg beside the load. One such technique is the straddle technique, in which the foot of the second leg is placed behind the load. To our knowledge, only one study[16] investigated this technique, with only one specific object at one specific height; that study showed no advantage of the straddle technique over the stoop technique. A third strategy for bringing L5–S1 closer to the load is to combine placing one leg beside the load with bringing the knee of the leg that remains behind the load to the floor. This strategy could further reduce the horizontal distance between the load and L5–S1 as well as allow the maintenance of an upright trunk

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All authors provided concept/idea/research design, data collection and analysis, and consultation (including review of manuscript before submission). Dr Kingma, Mr Faber, and Dr Bakker provided writing. Dr van Dieën provided project management and facilities/equipment.

The study was approved by the ethics review board of the Faculty of Human Movement Sciences, Vrije Universiteit.

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posture. This technique, which we refer to as the "kneeling technique," has not, to our knowledge, been investigated before. A potential disadvantage of this technique, especially when lifting wider loads, may be the development of substantial asymmetrical low back loading.

The aim of this study was to compare the straddle technique and the kneeling technique with stoop lifting and squat lifting with respect to the effects on kinematics, 3-dimensional (3-D) moments at the L5–S1 joint, and spinal compression and shear forces at this joint. We hypothesized that placing one leg beside the load to be lifted reduces spinal loading but induces asymmetrical loading when lifting wider loads.

Method

Subjects

After signing an informed consent form, 12 young men with no history of low back pain (age=26.1 years, SD=4.7 years; weight=68.7 kg, SD=6.3 kg; height=1.78 m, SD=0.04 m) participated in this study. Subjects (most of them were students) were recruited by "asking around," and they were paid for their participation. Subjects were unaware of the specific aim or hypothesis of this study. Researchers were skilled in instructing lifting techniques. Two of the researchers were physical therapists with extensive experience in biomechanical analysis and ergonomics, and 2 researchers were human movement science students working under the supervision of the senior researchers. These students received standardized training in teaching lifting techniques.

Experimental Design

The experiment consisted of 2 repetitions of lifting movements with 20-kg boxes (crates). The lifting movements differed in lifting technique (4 techniques), initial hand height (2 heights), and dimensions of the box used (2 box dimensions). The lifting techniques were: (1) a stoop technique (lifting with the knees extended), (2) a squat technique (bending the knees), (3) a straddle technique (lifting while placing the left foot on the left side of the box and the right foot behind the box), and (4) a kneeling technique (lifting while placing the left foot on the left side of the box and kneeling on the right knee behind the box). In all techniques except the stoop technique, subjects were instructed to hold the back as upright as possible. The 2 boxes were a narrow box (300 mm; a single crate mounted on a wooden board) and a wide box (600 mm; a double crate mounted on a wooden board). Both boxes were 200 mm deep and 270 mm high. For the stoop and squat lifting techniques, subjects were instructed to lift the narrow box between their feet, but they were instructed not to lift the wide box between their feet. The lifting techniques are illustrated in Figure 1.

Procedure

Before the experiment, videotaped instruction was given to show the 4 different lifting techniques. Next, subjects practiced the lifting techniques while receiving feedback until they mastered each of the techniques. Unlike the procedure applied by Kingma et al,[10] verbal instructions (including the instruction to maintain the trunk as upright as possible in all techniques except for the stoop technique) were repeated before each lift during the experiment.

The boxes had been placed on a shelf, suspended 50 mm above the surface of the force plate on which the subjects stood. All lifts were performed with an initial hand height of 290 mm (boxes were grabbed in a symmetrical way at their handles) and with an initial height of 50 mm (boxes were grabbed in a symmetrical way at their lower edges). Each lifting movement started with the subject in an upright standing posture. After the start of data collection, the subject stepped forward and, using the instructed technique, lifted the box to a height that allowed the subject to stand upright with slightly flexed arms. After the recording stopped, the subjects placed the box back on the shelf. The order of lifting technique, initial hand height, and box width was randomized over subjects. Subjects were free to select their preferred lifting speed.

Dynamic 3-D Linked Segment Model

A dynamic 3-D linked segment model was used to estimate net moments at the L5–S1 intervertebral disk. This model has been described in detail elsewhere[17] and has been internally validated by comparing a top-down to a bottom-up calculation of net moments. In addition, model results have been compared to independent net moment estimations with an electromyography (EMG)-based model and a neural network-based model.[7] The current model uses anthropometric data as described by McConville et al,[18] combined with force-plate data (measured at 500 Hz with a custom-made force plate measuring 1.0 × 1.0 m) and kinematics from light-emitting diode markers on cuffs to follow the lower-body segments (feet with lower legs, upper legs, pelvis, and trunk) during movement. To optimize visibility, markers on the cuffs were attached to small metal plates mounted to the cuffs with a double-hinge joint.

Trajectories of the cuff markers were recorded at 100 Hz and synchronized with force-plate signals by use of an automated 3-D movement registration system (Optotrak*; SD of system accuracy, <0.05 mm) with 3 arrays of 3 cameras. Before the measurements were obtained for each subject, the force plate and the Optotrak system were calibrated and cuff markers were related to ana-

* Northern Digital Inc,103 Randall Dr, Waterloo, Ontario, Canada.

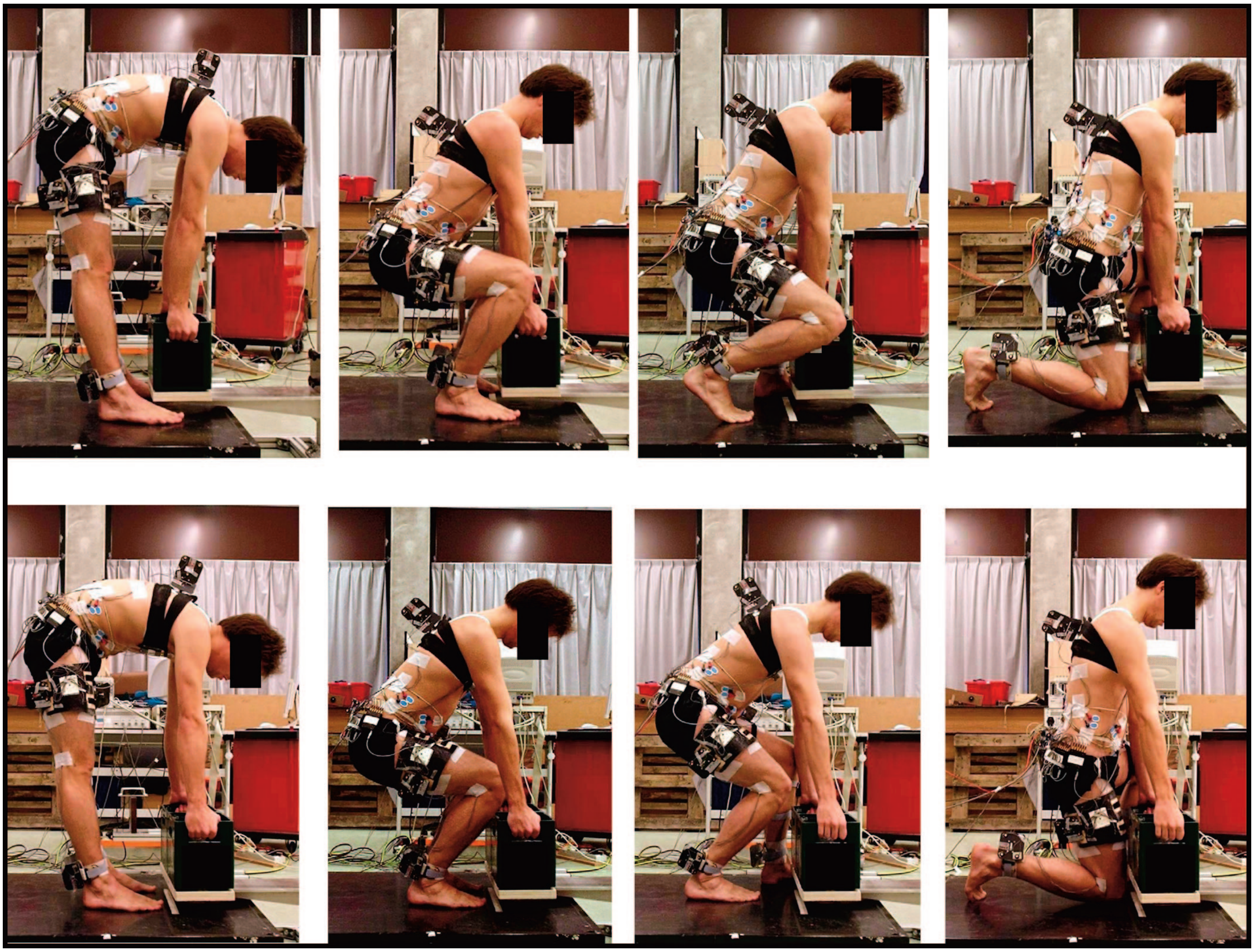

Figure 1.
Photographs showing a subject lifting a 20-kg box with the stoop technique (first column), squat technique (second column), straddle technique (third column), and kneeling technique (last column). The top row shows lifts with a 300-mm box (a single crate mounted on a wooden board); the bottom row shows lifts with a 600-mm box (a double crate mounted on a wooden board). Note that only the lifts at the 290-mm initial hand height are shown. For the 50-mm lifts, the initial crate position was the same, but subjects grabbed the crate at the left and right bottom edges. Photographs were taken before lifting, when the box was still resting on the (aluminum) shelf hanging over the force plate.

tomical landmarks by making a short recording while pointing at each landmark[19] with a pointer containing 6 markers. Marker data were low-pass filtered by use of a bidirectional second-order Butterworth filter at a cutoff frequency of 10 Hz. A global equation of motion (rather than a segment-by-segment calculation) was used as described by Hof[20]:

$$\mathbf{M}_{L5\text{-}S1} = -\mathbf{M}_g - (\mathbf{r}_g - \mathbf{r}_{L5\text{-}S1}) \times \mathbf{F}_g - -\sum_{i=1}^{q}[(\mathbf{r}_i - \mathbf{r}_{L5\text{-}S1}) \times \boldsymbol{m}_i\mathbf{g}] + \sum_{i=1}^{q}[(\mathbf{r}_i - \mathbf{r}_{L5\text{-}S1}) \times \boldsymbol{m}_i\mathbf{a}_i] + \sum_{i=1}^{q} \mathrm{d}(\mathrm{I}_i\boldsymbol{\omega}_i)/\mathrm{dt},$$

where $\mathbf{M}_{L5\text{-}S1}$ is the net moment at the L5–S1 joint, $\mathbf{r}_g$ is the vector to the point of application of the ground reaction force, $\mathbf{F}_g$ is the ground reaction force, $\mathbf{r}_{L5\text{-}S1}$ is the vector to the L5–S1 joint, $\mathbf{r}_i$ is the vector to the center of the mass of segment i, $\boldsymbol{m}_i$ is the mass of segment i, $\mathbf{a}_i$ is the acceleration of segment i, $\mathbf{g}$ is gravity, q is the number of segments of the lower body up to L5–S1, I_i is the inertia tensor of segment i, $\boldsymbol{\omega}_i$ is the angular velocity of segment i, d(. . .)/dt is the time derivative of the expression within parentheses, and $\mathbf{M}_g$ is the ground reaction moment measured by the force plate. Boldface type represents vectors in the equation. This moment is non-0 around the vertical axis only. The L5–S1 joint was chosen as the level of analysis because it is the lumbar joint that is expected to undergo the largest loads. The global equation of motion allowed the use of 1 instead of 2 force plates. Anatomical axes of the trunk and pelvis were defined as follows: positive x-axis (lateral flexion) forward; positive y-axis (flexion-extension) to the left;

and positive z-axis (twisting) upward. Net moments were expressed in the pelvic axis system. The trunk movement relative to the pelvis was decomposed in the order y-x-z.

3-D EMG-Driven Trunk Model

Fourteen pairs of surface EMG electrodes were attached to the skin after abrasion and cleaning with alcohol (Ag-AgCl electrodes†; interelectrode distance, 20 mm). Electrodes were bilaterally attached ventrally over the rectus abdominis muscle (at the level of the umbilicus), the internal oblique muscle (just superior to the inguinal ligament), and the anterior (approximately 15 cm cranial of the anterior iliac spine) and lateral (midaxillary line, halfway between the iliac crest and the lowest edge of the rib cage) parts of the external oblique muscle. Dorsally, electrodes were attached over the iliocostalis lumborum muscle (6 cm lateral to L2) and over the longissimus thoracis pars lumborum (3 cm lateral to L1) and pars thoracis (4 cm lateral to T10) muscles.

Before the actual experiment, subjects performed 7 maximum isometric contractions of the trunk muscles, 3 times, as described by McGill.[21] The EMG data were recorded (Porti-17TM‡; input impedance, 10^{12} Ω; common mode rejection ratio, >90 dB), band-pass filtered (10–400 Hz), converted from analog to digital (22 bits at 1,000 Hz), and stored synchronized to Optotrak and force-plate data. Offline, EMG signals were high-pass filtered (20 Hz), full-wave rectified, and low-pass filtered at 2.25 Hz.[22] The EMG data were normalized to maximum voluntary contractions and used as the input of an EMG-driven trunk muscle model. The model has been described in more detail elsewhere[23,24] and consists of a compilation of anatomical data described by Stokes and Gardner-Morse[25] for the back muscles and by McGill[26] for the abdominal muscles. The transversus abdominis muscle and the psoas major muscle were excluded because it is unlikely that their activity can be estimated reliably from surface EMG data and because their moment-producing capacity is limited. The latissimus dorsi muscle was omitted because a reliable indication of its force would require modeling the shoulder in detail and because its capacity to generate an extensor moment at the lumbar spine is only very small.[27] After exclusion of the above-mentioned muscles, the model consisted of 90 muscle slips crossing the L5–S1 joint. The model was scaled to individual body height. For muscle slips crossing the L4 and T12 levels, nodes were used as points about which these long muscles were wrapped. In this way, the muscles followed the lumbar curvature during motion.

† Sentry Medical Products, 17171 Murphy Ave, Irvine, CA 92714.

‡ TMS, Zutphensestraat 57, Oldenzaal, the Netherlands.

After assigning each of the 90 muscle slips to 1 of the 14 EMG signals, muscle forces were estimated as the product of the assumed muscle maximum stress (a single value for all muscles, which was adjusted for each subject to obtain the best fit between net moments and muscle moments), normalized EMG amplitude, and correction factors for the instantaneous muscle length[28] and contraction velocity[29] that had been calculated with 3-D trunk lumbar angles. Finally, to obtain compression and shear forces at the L5–S1 intervertebral joint, muscle forces and net reaction forces were summed after being projected on the axis system connected to the L5–S1 disk. For convenience, shear forces pushing the trunk forward were indicated as positive, and absolute values were taken for lateral shear forces.

Data Analysis

From the time series of the net moment around the L5–S1 joint, peak values were calculated for the extending, lateral flexion, and torsion components of the net moment as well as for the total moment (ie, the vector sum of the 3 moment components). Furthermore, at the instant of peak total moment, trunk inclination, lumbar flexion, lateral flexion, torsion, and the horizontal distance from L5–S1 to the load center of mass were determined. Finally, time series of the forces at the L5–S1 joint, calculated with the EMG-assisted trunk model, were used to calculate peak compression forces and peak forward and lateral shear forces.

For the values described above, as well as for co-contraction (the flexor moment generated by the abdominal muscles at the instant of peak compression, expressed as a percentage of the net extensor moment), repeated-measures analyses of variance (ANOVAs) were applied (one ANOVA for each dependent variable) with lifting technique (4 levels), initial hand height (2 levels), and box width (2 levels) as independent variables. A significance level of $P<.05$ was used. Each lift was performed twice and all variables were averaged over those 2 lifts before statistical analyses were applied. Finally, differences between individual lifting techniques were tested with Tukey honestly significant difference *post hoc* tests.

Results

The results of repeated-measures ANOVAs for all dependent variables are shown in the Table.

Moments

In this study, we hypothesized that placing one leg beside the load to be lifted reduces spinal loading but that it induces asymmetrical loading when one is lifting wider loads. The hypothesis was corroborated only in part. Net total moments showed a main effect of lifting technique as well as interactions of lifting technique with

Table.
Results of Repeated-Measures Analyses of Variance Representing Effects of Box Width, Initial Hand Height, and Lifting Technique[a]

	P Value for:												
	Moments				Spinal Forces			Lumbar Motion					
Parameter	Total	Extension	Lateral Flexion	Torsion	Compression	Forward Shear	Lateral Shear	Trunk Inclination	Lumbar Flexion Angle	Lumbar Lateral Flexion Angle	Lumbar Torsion Angle	Horizontal Distance From L5–S1 to Box	Co-contraction
Box width (W)	**<.001**	**<.001**	**<.001**	**.024**	**<.001**	.129	**.012**	**<.001**	**.001**	.248	.804	**<.001**	.167
Initial height (H)	**<.001**	**<.001**	.051	**<.001**	**<.001**	**.033**	.508	**<.001**	**<.001**	.136	**.036**	**.001**	.161
Lifting technique (T)	**<.001**	**<.001**	**<.001**	**<.001**	.630	**.043**	**<.001**	**<.001**	**<.001**	**.012**	**.001**	**<.001**	**<.001**
W × H	.068	.109	.710	.837	.219	**.022**	.247	.314	.453	.535	.174	**.006**	.687
W × T	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**.034**	.062	**<.001**	**.019**	.053	**<.001**	**<.001**	**<.001**
H × T	**<.001**	**<.001**	**.009**	**<.001**	**<.001**	**.037**	.490	.559	**<.001**	.126	.289	**<.001**	**.003**
W × H × T	.507	.682	.789	.670	.629	**.002**	.680	.726	**.032**	.322	.079	.102	.118

[a] Values in bold type indicate significant effects ($P<.05$).

box width and initial hand height (Table, Fig. 2). With respect to the main effect, *post hoc* tests revealed that the kneeling technique resulted in net total moments that were, on average, 7% to 10% smaller than those resulting from the other lifting techniques ($P<.001$). More importantly, large interaction effects were seen. For instance, when the subjects lifted the narrow box from 290 mm, stoop lifting resulted in about 20% higher total moments than did squat lifting, whereas the opposite was the case when the subjects lifted the wide box from 50 mm. For lifting of the narrow box with the squat technique, the feet had been placed on each side of the box. As a result, neither the straddle technique nor the kneeling technique reduced the total moments in comparison with the squat technique. For lifting of the wide box, the feet had not been placed beside the box. Consequently, the straddle technique did reduce the total moments in comparison with the squat technique (with 19 N·m [SD=20 N·m] for lifting from 290 mm and with 23 N·m [SD=20 N·m] when lifting from 50 mm). The kneeling technique further reduced the total moments in comparison with the straddle technique (with 24 N·m [SD=21 N·m] for lifting from 290 mm and with 27 N·m [SD=22 N·m] for lifting from 50 mm). However, for lifting of the wide box from 50 mm, the total moments did not differ between the kneeling technique and the stoop technique.

The asymmetrical components of the net moments (the lateral flexion and torsion moments) were affected by lifting technique, initial height, box width, and interactions between lifting technique and box width and height (Table). The kneeling technique caused asymmetrical moments that were about 2 or more times as high as those caused by the other techniques, for the lateral flexion component in all conditions and for the torsion component when subjects lifted from 50 mm (Fig. 2).

Spinal Forces

Although the overall pattern of compression forces over conditions and lifting techniques (Fig. 3) had the same appearance as the pattern of total moments, there were some relevant deviations. There was no main effect of lifting technique on L5–S1 compression forces. This finding was unlike the finding for total moments. The most substantial difference with the pattern found for net total moments was a relatively higher loading for the kneeling technique.

When subjects lifted the narrow box from 290 mm, the squat technique resulted in lower compression forces than did the stoop technique and the kneeling technique. The opposite was the case when subjects lifted the wide box from 50 mm. When subjects lifted the narrow box from 50 mm, no difference between lifting tech-

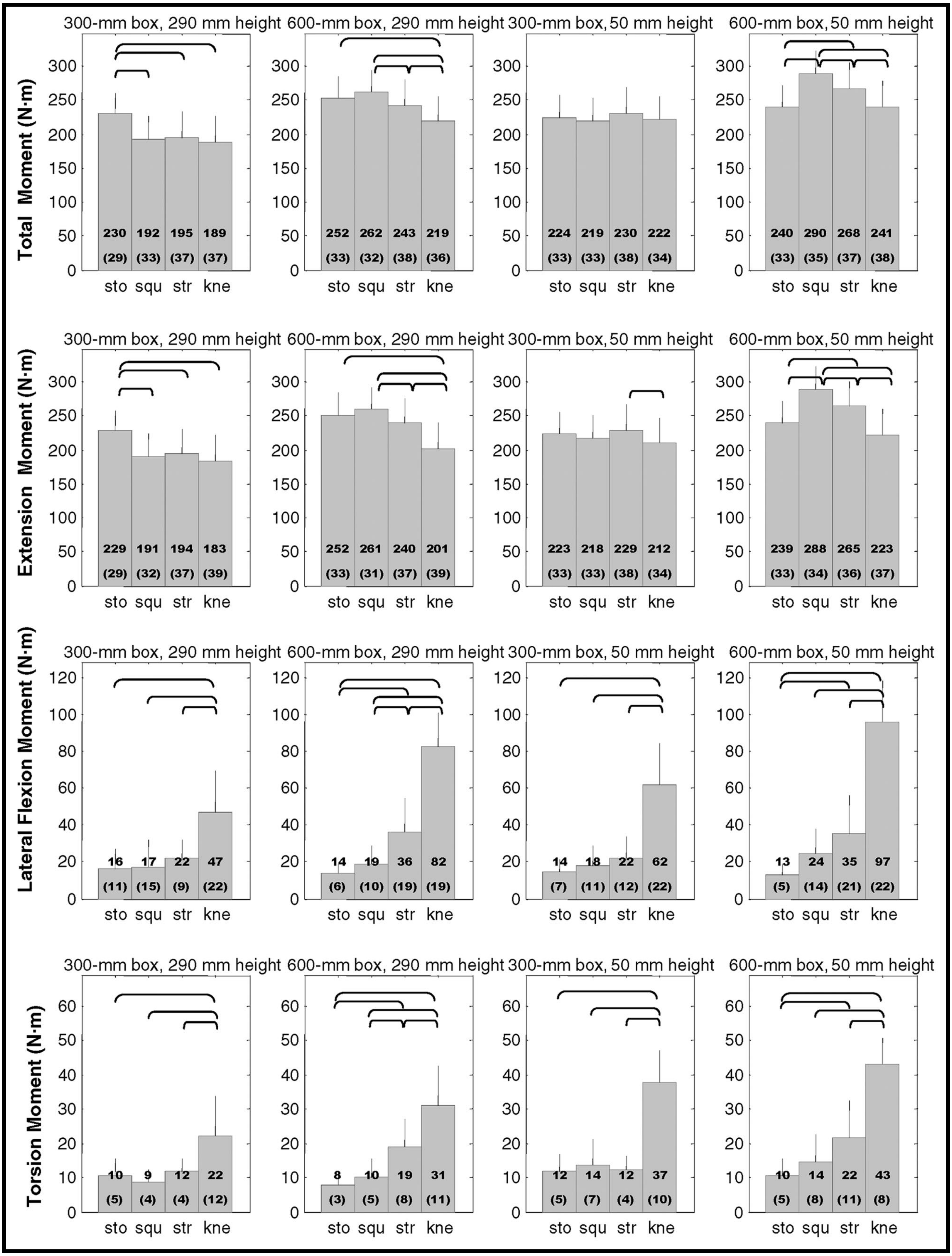

Figure 2.
Peak values, averaged over subject, for the total moment (row 1) and the extension (row 2), lateral flexion (row 3), and torsion (row 4) components of the net moment when subjects lifted a 20-kg box using stoop (sto), squat (squ), straddle (str), and kneeling (kne) techniques. Boxes of 2 dimensions (widths of 300 and 600 mm) were lifted from 2 initial hand heights (290 and 50 mm). Numbers indicate the rounded value for each bar, and the number in brackets and the error bar indicate 1 standard deviation. Each bracket above the bars connects 2 lifting techniques that were significantly different.

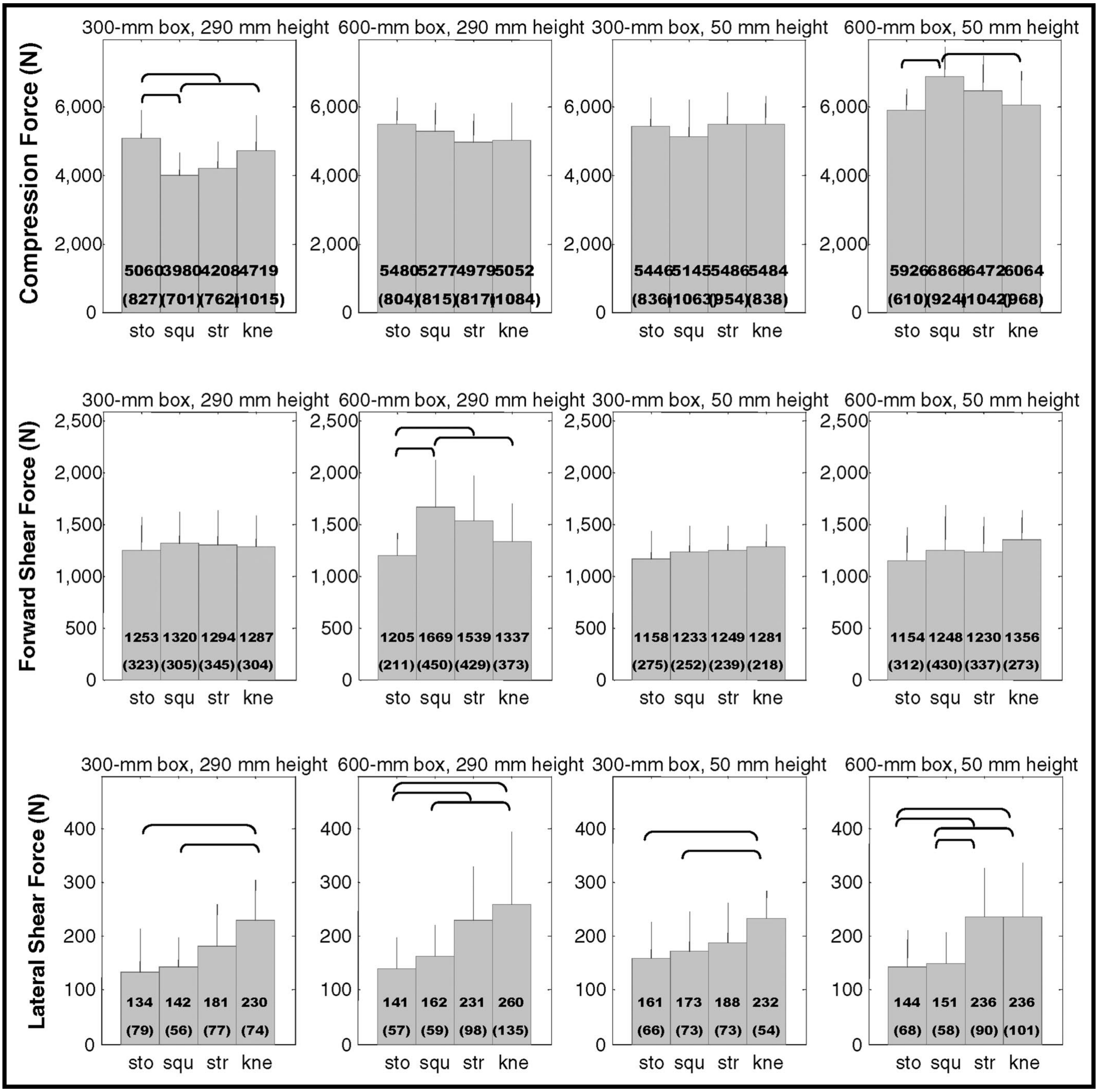

Figure 3.
Peak values, averaged over subjects, for the estimated compression force (row 1), the forward spinal shear force (row 2), and the lateral shear force (row 3) when subjects lifted a 20-kg box using stoop (sto), squat (squ), straddle (str), and kneeling (kne) techniques. Boxes of 2 dimensions (widths of 300 and 600 mm) were lifted from 2 initial hand heights (290 and 50 mm). Numbers indicate the rounded value for each bar, and the number in brackets and the error bar indicate 1 standard deviation. Each bracket above the bars connects 2 lifting techniques that were significantly different.

niques was found. This finding was the same as the finding for net total moments. When subjects lifted the wide box from 290 mm, none of the differences between any pair of lifting techniques reached significance. This finding was unlike the finding for total moments.

Forward shear loads showed substantial differences between lifting techniques only when subjects lifted the wide box from 290 mm. In that condition, the straddle and squat techniques resulted in higher forward shear forces than did the stoop technique, and the squat technique resulted in higher shear forces than did the kneeling technique.

Lateral shear forces were below 300 N for all lifting techniques in all 4 initial height and box width conditions. Consistent with the lateral flexion moments, lateral shear forces were higher for the kneeling technique than for the stoop and squat techniques in all 4 initial height and box width conditions. For the straddle technique, this was the case only when subjects lifted the wide box.

Trunk Motion

Lumbar flexion and trunk inclination were larger when subjects lifted the wide box than when they lifted the narrow box and were larger when subjects lifted from 50 mm than when they lifted from 290 mm (Table, Fig. 4). In all 4 initial height and box width conditions, the stoop technique resulted in more lumbar flexion and more trunk inclination than all other techniques. The kneeling technique resulted in less trunk inclination than the other techniques, but the difference with the straddle technique was not significant for lifting of the narrow box. Lumbar flexion did not differ significantly among the squat, straddle, and kneeling techniques.

The findings with regard to asymmetrical lumbar motion were consistent with the asymmetrical moment components and lateral shear forces. Generally (although not always significantly; Fig. 4), for lifts with the wide box, the straddle technique resulted in more lateral flexion and torsion than did the stoop or the squat technique. For lifts with the narrow box, the kneeling technique resulted in more lumbar torsion than did the other techniques.

Distance

In 9 of 12 paired comparisons, the horizontal distance from L5–S1 to the box was significantly smaller with the stoop lifting technique than with the other lifting techniques (Fig. 5). When subjects lifted the wide box, the straddle technique and the kneeling technique were more effective in reducing the horizontal distance from L5–S1 to the box than was the squat technique. However, when subjects lifted the narrow box, for which squat lifting was performed with the feet beside the box, the opposite was the case.

Co-contraction

The level of co-contraction was highly affected by lifting technique (Table, Fig. 5). *Post hoc* tests showed that the level of co-contraction was higher with the kneeling technique ($P<.001$) than with the other 3 techniques. The level of co-contraction was lower with the stoop technique than with the other 3 techniques ($P<.001$).

Discussion and Conclusions

In this study, 2 lifting techniques that have received little attention in the literature were compared with stoop lifting and squat lifting. This comparison was made for 2 load size conditions and 2 initial vertical hand positions. In line with the results of other studies, peak net moments and compression forces increased when subjects lifted wider loads[10] and when the initial hand position was lower.[9–11,30] The main reason to investigate the straddle technique and the kneeling technique in this study was that those techniques might allow subjects to bring the pelvis closer to the load than in the squat technique while keeping the trunk more upright than in the stoop technique. The horizontal distances from L5–S1 to the box showed that the former was indeed the case for the wide box but that the opposite appeared to be the case for the narrow box. The resulting low back loading is discussed in more detail below.

Spinal Compressive Loading

Over all 4 hand height and load size conditions, the kneeling technique resulted in smaller net total moments than did the other 3 techniques. However, L5–S1 compression forces did not show this overall advantage for the kneeling technique. To facilitate the interpretation of differences in effects of lifting technique between net total moments and compression forces, co-contraction was analyzed. This analysis showed that co-contraction contributed to the absence of an overall advantage of the kneeling technique for L5–S1 compression forces. The level of co-contraction was higher for the kneeling technique than for the other 3 techniques, especially for lifting from 290 mm. This co-contraction caused a higher level of spinal compression with the kneeling technique than with the other techniques. This increased co-contraction in the kneeling technique may be related to the asymmetry of the posture. In addition, most subjects indicated that the kneeling technique felt less stable than the other techniques; this factor also may have enhanced the level of co-contraction.

The effects of interactions between lifting technique and both load size and initial hand position were much more prominent than the main effect of lifting technique. The lifting technique resulting in the highest total moments and compression forces and the lifting technique resulting in the lowest total moments and compression forces varied over the 4 box width and initial hand height combinations. The main reason for those interactions is that total moments and compression forces appeared to be much more dependent on lifting height and on box width in the squat and straddle techniques than in the stoop technique. This difference between lifting techniques in sensitivity of spine loading to height and width can be attributed in part to trunk inclination and L5–S1 distance. With respect to trunk inclination, Figure 4 shows that trunk inclination was higher with all lifting techniques when subjects lifted the wide box than when they lifted the narrow box and when they lifted with an initial hand position of 50 mm than when they lifted with

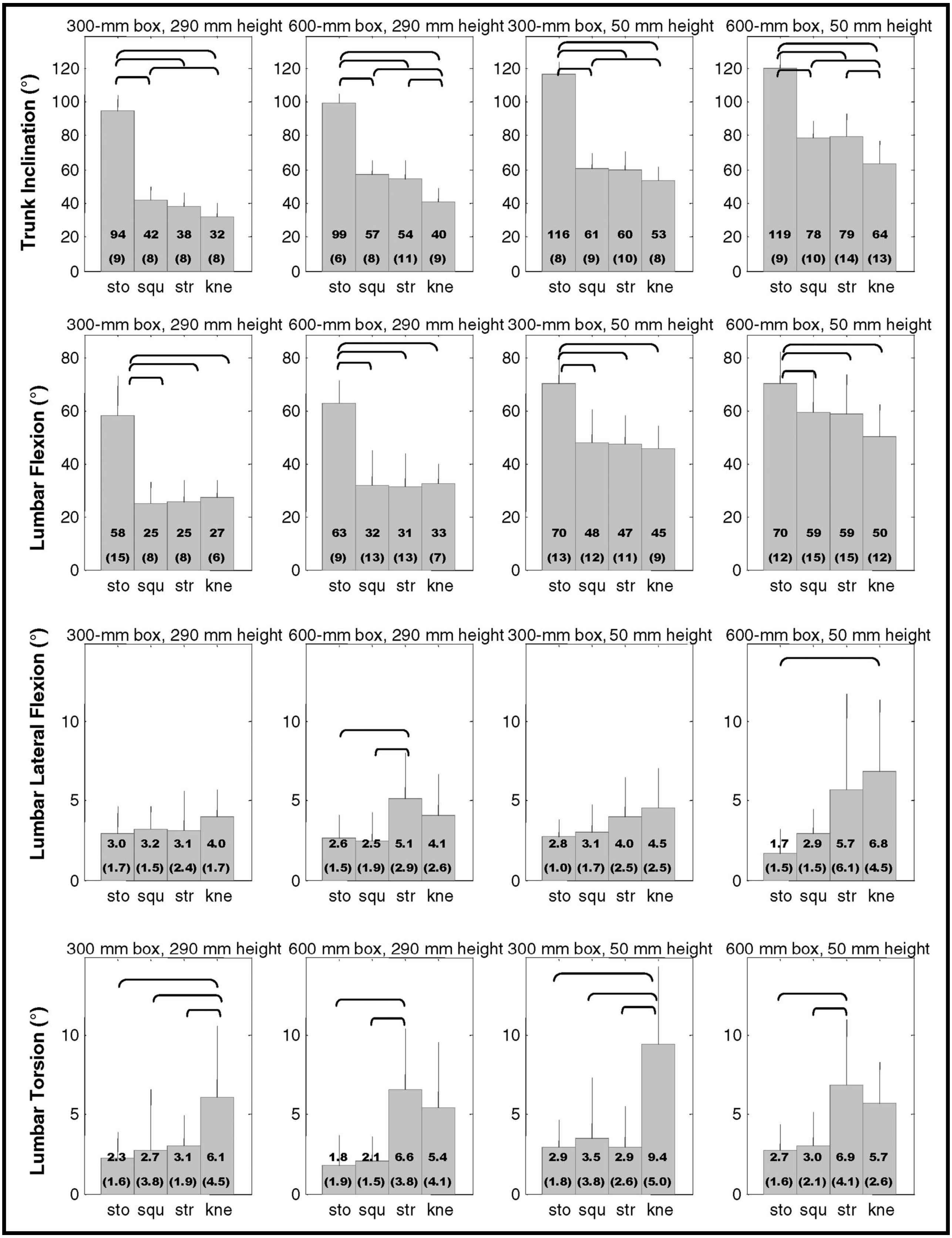

Figure 4.
Values at the instant of the peak total moment, averaged over subjects, for the trunk inclination (row 1) and for flexion (row 2), lateral flexion (row 3), and torsion (row 4) of the lumbar spine when subjects lifted a 20-kg box using stoop (sto), squat (squ), straddle (str), and kneeling (kne) techniques. Boxes of 2 dimensions (widths of 300 and 600 mm) were lifted from 2 initial hand heights (290 and 50 mm). Numbers indicate the rounded value for each bar, and the number in brackets and the error bar indicate 1 standard deviation. Each bracket above the bars connects 2 lifting techniques that were significantly different.

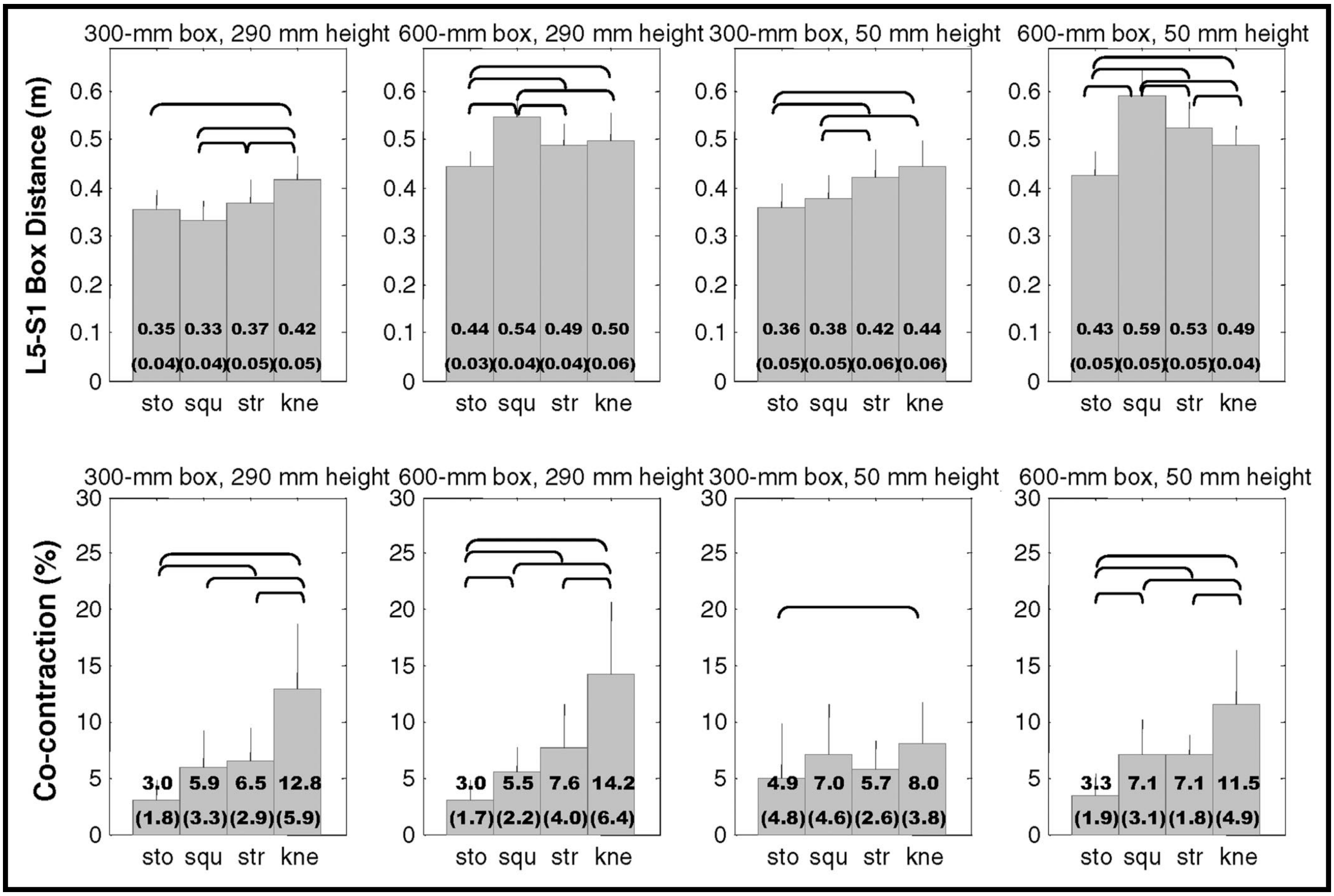

Figure 5.
Values, averaged over subjects, for the horizontal distance from L5–S1 to the box center (values at the instant of the peak total moment) and for co-contraction (values at the instant of the peak compression) when subjects lifted a 20-kg box using stoop (sto), squat (squ), straddle (str), and kneeling (kne) techniques. Boxes of 2 dimensions (widths of 300 and 600 mm) were lifted from 2 initial hand heights (290 and 50 mm). Numbers indicate the rounded value for each bar, and the number in brackets and the error bar indicate 1 standard deviation. Each bracket above the bars connects 2 lifting techniques that were significantly different.

an initial hand position of 290 mm. This increase in trunk inclination caused an increase in the moment arm of the trunk center of mass for the squat, straddle, and kneeling techniques but not for the stoop technique. The reason is that the trunk inclination in the stoop lifting technique was already over 90 degrees when subjects lifted the narrow box from an initial hand position of 290 mm, whereas this was not the case in the other lifting techniques.

An additional reason for the interaction of lifting technique with box width was that the squat technique was more sensitive to box width than were the other techniques. When subjects lifted the wide box, especially when the initial hand position was low, they needed to maintain clearance for the knees by adopting a posture with a large horizontal distance between the box and the pelvis, because this box width did not allow lifting between the knees. A comparable problem occurred when subjects lifted the wide box with the straddle technique; unlike the situation with lifting of the narrow box, the knee of the leg that was placed behind the load could not be rotated outward far enough to bring the knee beside the load. Thus, the required clearance of the knee of the leg that was placed behind the box forced the subjects to move the pelvis backward. Consequently, the moment arm of the load relative to the L5–S1 joint increased with wider loads when the straddle technique was used. As a consequence of the interactions described above, stoop lifting resulted in the highest total moments and compression forces when subjects lifted the narrow box at a 290-mm height, whereas squat lifting resulted in the highest total moments and compression forces when subjects lifted the wide box at a 50-mm height. When subjects lifted the narrow box at a 50-mm height, no significant differences between lifting techniques were found.

For comparisons of spinal loading over task conditions or over lifting techniques, effects on spinal loading should be compared with effects on the strength of the spinal structures. Compression forces in this study are within the range of values that can cause end plate fractures *in vitro*.[31] Facilitated by the nonlinear relationship between compression force and population at risk, the effects of lifting condition and lifting technique, as observed in our study, can have substantial effects on the population at risk.[31] As such, those effects are clinically significant. However, compressive strength may be affected by task conditions and lifting techniques through differences in posture. Unfortunately, little is known about the effects of spinal posture on strength. Especially in stoop lifting, high levels of lumbar flexion are reached. Adams et al[32] reported a reduced compressive strength beyond 75% of the maximum *in vitro* flexion. However, according to Adams and Hutton,[33] it is unlikely that such flexion is reached *in vivo*. Nevertheless, full *in vivo* lumbar flexion may result in substantial stresses on the posterior annulus and on vertebral ligaments,[34] and these stresses could increase the risk of soft-tissue injury in or around intervertebral disks.

With respect to asymmetry in lumbar spine posture, both the kneeling technique and the straddle technique were found to result in somewhat more asymmetry than the stoop technique and the squat technique under most conditions. Epidemiologic work has shown that asymmetry in lifting is a separate risk factor for acute disk prolapse.[35] However, we are unaware of experimental work showing reduced spinal strength under lumbar torsion or lateral flexion of the limited magnitude found in the present study. Lumbar torsion especially may even have been overestimated in the present study because the markers on the trunk were mounted at about T9 rather than T12.

Besides a slightly asymmetrical posture during peak loading, especially the kneeling technique resulted in substantial asymmetrical moment components (Fig. 2). As a result, lateral shear forces were higher with the kneeling technique than with the other techniques. However, the magnitude of the lateral shear forces was relatively low (Fig. 3), making it unlikely that those forces, by themselves, could harm the lumbar spine. In addition to the implications for lateral forces, the asymmetrical moments likely contributed to the higher level of co-contraction that was found with the kneeling technique.

Spine Shear Loading

Substantial forward shear forces, approximately between 1,100 and 1,700 N, were found at the L5–S1 joint. Those forces are in the range of values that have been reported to cause bony failure *in vitro*.[36,37] The magnitude of the forces at the L5–S1 joint is in line with previous work.[9,10,38,39] These forces are much higher than the forces reported for the L4–L5 joint,[10,40] a difference that may be explained by the more forward inclined orientation of the L5–S1 disk.

Forward spinal shear loading in 3 of 4 box width and initial height conditions was unaffected by lifting technique. Likewise, Kingma et al[10] reported no effect of lifting technique on L5–S1 shear forces. Kingma et al[10] decomposed shear forces at the L5–S1 joint into muscular and net reaction force components. They showed that in lifts with more trunk flexion (such as the stoop technique), a larger net reaction shear force was compensated for by a smaller muscular shear force, resulting in total shear forces being unaffected by lifting technique. In the present study, only when subjects lifted the wide box from the 290-mm height were substantial differences between lifting techniques seen. In this condition, shear forces were lower with stoop lifting than with squat lifting and straddle lifting. This result may have been caused by the large difference in lumbar flexion between the stoop lifting technique and the other lifting techniques in this condition. The larger lumbar flexion with stoop lifting decreased the muscular component of the forward shear force relative to the L5–S1 joint. When subjects lifted the narrow box from the 290-mm height, lumbar flexion also was much larger with stoop lifting than with the other techniques. However, this condition did not result in lower shear forces with stoop lifting, because of the relatively large moments requiring large muscle forces.

Some limitations of the present study should be mentioned. First, asymmetrical load placement relative to the subject was not considered, whereas approximately half of industrial lifting tasks involve more than 10 to 15 degrees of asymmetry in load placement.[41] Furthermore, we studied only a relatively small group of healthy young male subjects. The interactions between lifting technique and box width and initial hand height, as found in the present study, may not be the same in females.[30,42] In addition, although the role of lifting technique in this issue has not been clarified, back loading patterns attributable to variations in task constraints have been shown to differ between people with back pain and healthy people.[43]

In conclusion, the present study showed that no single lifting technique can be advised for all task conditions. Especially with the squat lifting technique, low back loading varied markedly with box width and initial hand height. The straddle and kneeling techniques were introduced because they might be able to reduce the horizontal distance from the load to the low back. However, when subjects lifted a narrow box, the opposite appeared to be the case, so that the straddle and kneeling techniques did not reduce low back loading in comparison with squat lifting. A wide box did not allow placement of the feet beside the box during squat lifting. As a result, the straddle technique and the kneeling technique were successful in reducing the horizontal distance from the low back to the load in comparison with the squat lifting technique, thereby also reducing net total moments. However, this result was obtained at the cost of substantial asymmetrical load components and a substantial amount of co-contraction. Consequently, compression forces did not differ as much as net total moments between the squat technique and the straddle or kneeling technique when subjects lifted a wide box.

Notably, lifting condition (height and width) had more influence on compression forces than did lifting technique. When subjects lifted the wide box from 50 mm, the lowest compression force was almost 6,000 N (ie, when the stoop technique was used). In contrast, when subjects lifted the narrow box from 290 mm, the highest compression force was only about 5,000 N (again, when the stoop technique was used). Thus, the most important advice with regard to lifting is to avoid lifting wide objects from floor level. Second, when objects can be lifted between the feet, squat lifting is preferred from the perspective of compression forces. Third, when lifting a wide object from the floor cannot be avoided, squat lifting is not advised, and the kneeling technique may be preferred in order to limit compression forces without the need for full lumbar flexion, as in stoop lifting.

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